Fisheries Research in Algonquin Park – The 90s

Abstracts of a Symposium held at the Algonquin Park
Visitor Centre, Dec 12-13, 2001

PRFO Occasional Paper Series
Occasional Paper No. 2
October, 2002

A Joint Publication by Algonquin Provincial Park and
Parks Research Forum of Ontario

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PREFACE

This is the second of a series of joint publications for parks and protected areas issued by the Parks Research Forum of Ontario (PRFO) in co-operation with Forum partners. Through this cooperative effort, PRFO supports and facilitates the conduct and publication of research relevant to parks and protected areas and the dissemination of such research for wider conservation use.

The specific objectives of PRFO are:

- Promote research to improve understanding, planning, management and decision-making for parks and protected areas;
- Encourage educational and training activities relating to parks and protected areas;
- Facilitate more co-operation in parks and protected areas research;
- Establish a meeting place for people involved in parks and protected areas research;
- Exchange information on a regular basis among people involved in parks and protected areas research; and,
- Monitor and report on parks and protected areas.

In working toward these objectives PRFO has focused to date on the holding of an annual meeting and publication of the proceedings.

On December 12-13, 2001, a symposium was held, which focused on fisheries research in Algonquin Park throughout the 1990s. This report, now issued as PRFO Occasional Paper No. 2, contains abstracts of the symposium presentations. Although the amount of information that the reader can gain from this publication is limited, it does present an opportunity to follow up with park staff or the authors. The main benefit is that the publication will make Algonquin fisheries research more widely known. Such research is of value for its own sake and also in contributing to better planning, management and decision-making in the future. We are very grateful for the support of Ontario Parks in this project.

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INTRODUCTION

From "Fish and Fishing in Cache Lake" to Stable Isotopes and Geographic Information Systems – An Introduction to the Algonquin Symposium

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Canada's most influential science activity, as measured by journal rankings and citation patterns, is research in fisheries and aquatic science. No other area of scientific undertaking in Canada can match this position globally. For those of us working in this area, this position in the world is both the standard we strive to meet and one that research in Algonquin Park has contributed to over the years. Contained in this publication are the recent contributions to a symposium on fisheries and aquatic science in Algonquin Park that continue to highlight the high standards that we share in this discipline. A full appreciation of just how this ranking can come about is exemplified in the history of fisheries and aquatic science in Algonquin Park.

This research has a long history and is closely tied to the story of the Harkness Laboratory of Fisheries Research. The first organized effort in this area was J.R. Dymond's (Royal Ontario Museum) survey of Cache Lake that was published in 1935 as "Fish and Fishing in Cache Lake". The following year, Fred Fry (University of Toronto) began fieldwork at Lake Opeongo and surrounding lakes that served as the starting point for a research station that would eventually become known as the Harkness Laboratory of Fisheries Research, named after the first director, W.J.K. Harkness. Unlike most field stations and research programs, there is a published account of the first evening at the Opeongo site provided by one of Fred's graduate students, Richard Miller. His description of that night included many first impressions of the site and the task that lay before them. Among these was Fred Fry passing time that evening by reading aloud passages from Charles Darwin's *On the Origin of Species*. One couldn't imagine a more appropriate symbol to begin a field station and research program.

Since that time, field-based research out of 'the fish lab' has provided important contributions in fish population ecology and lake ecosystem ecology. It has also provided essential training for graduate and undergraduate students at many universities in Ontario who subsequently went on to careers in fisheries and aquatic science. The current contributions listed in this publication represent the range of activity underway in Algonquin Park, the new techniques employed, and the new insights gained from these approaches. It also represents well the tradition of graduate student training that has been present from the beginning.

The staff that worked at the fish lab over 60 years ago could not have anticipated the research summaries contained in this report. Geographic information systems employed to address landscape features influencing brook trout (*Salvelinus fontinalis*) distribution, stable isotopes used to reveal the structure of fish food webs in lakes, and biotelemetry of lake trout (*Salvelinus namaycush*) are all representative of a new wave in fisheries and aquatic science. Hydroacoustic surveys of zooplankton communities provide entirely new views of lake ecosystems. Important traditions at Harkness do continue in addition to these new approaches. The value of long-term research is strongly indicated in many of the summaries and this element of field-based research may be one of the most important lessons stemming from work at Harkness. Long-term research reveals new patterns simply from the advantage of time as well as more fully informing modern tools employed in fisheries and aquatic science.

While these reports represent leading edge work in fisheries and aquatic science in Algonquin Park today, it is tempting to consider what this kind of symposium will reveal in twenty years or so. There is a danger in attempting to make linear predictions of the future based on what is known now, however, one element is sure to be present. Specifically, the mix of new technology and long-term studies that is now proving successful should continue into the future. This perspective of 'one foot in the past with the other in the future' was recently symbolized for me on a recent visit to the Department of Ichthyology and Herpetology at the Royal Ontario Museum. When looking through old data on different fish species, E.J. Crossman pointed out to me that the desk I was using was the desk that J.R. Dymond had used so many years ago. Perhaps it served its purpose during the writing of "Fish and Fishing in Cache Lake" and many other summaries of Algonquin Park research. What it does now is symbolize the continuity of fisheries and aquatic research in Algonquin Park that sustains leading edge work.

ABSTRACTS

Biodiversity of Algonquin Park Fishes

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Algonquin Park has a depauparate fish fauna relative to other areas of southern Ontario. Only 49 species are native to the Park. This low number of species is the result of limited colonization opportunities following the last Ice Age and relatively cool current climate. Of the 49 species, only the American eel (*Anguilla rostrata*) is no longer present. It was last seen (and eaten) in the Park in 1936 and its loss is undoubtedly related to construction of dams in the lower reaches of the Petawawa and Madawaska rivers. Although the shortjaw cisco (*Coregonus zenithicus*) has been recorded in White Partridge Lake, recent analyses of this population indicate that it is likely a morph of the lake herring (*Coregonus artedii*) also found in the lake.

The distributions of the native species can be separated into five distinct patterns: 1) ubiquitous - found throughout the Park (e.g., creek chub (*Semotilus atromaculatus*), brook trout (*Salvelinus fontinalis)*); 2) Petawawa - found throughout the Petawawa drainage (e.g., fallfish (*Semotilus corporalis*), troutperch (*Percopsis omiscomaycus*)); 3) lower Petawawa - found only downstream from Cedar Lake (e.g., shorthead redhorse (*Moxostoma macrolepidotum*), walleye (*Stizostedion vitreum*)) of Lake Travers (e.g., rosyface shiner (*Notropis rubellus*), channel catfish (*Ictalurus punctatus*); 4) lowland margin-found only around the perimeter of the Park (e.g., central mudminnow (*Umbra limi*), ninespine stickleback (*Pungitius pungitius*)); and, 5) sporadic-found throughout the Park only in areas of suitable habitat (e.g., round whitefish (*Prosopium cylindraceum*), brassy minnow (*Hybognathus hankinsomi*)).

Within the last 150 years, eight species and one hybrid (splake) have been introduced to the Park, where four of these (hornyhead chub (*Nicomis biguttatus*), rainbow smelt (*Osmerus mordox*), smallmouth bass (*Micropterus dolomieui*) and largemouth bass (*Micropterus salmoides*)) have established reproducing populations. Unfortunately, the ranges of several native species (northern pike (*Esox lucius*), rock bass (*Ambloplites rupestris*), walleye (*Stizostedion vitreum*)) and introduced species (smallmouth bass (*Micropterus dolomieui*), largemouth bass (*Micropterus salmoides*)) continue to expand in the Park as a result of unauthorized transfer and subsequent natural dispersal. These species have the potential to seriously impact native fish communities.

The same processes that have limited species richness have also allowed unique populations and communities to develop in Algonquin Park. The Opeongo whitefish is a dwarf form of lake whitefish (*Coregonus clupeaformis*) described from Lake Opeongo. Distinct populations of brook and lake trout (*Salvelinus namaycush*) have been identified in the Park, including an interesting colour morph of lake trout (silver with no markings) in Kingscote Lake. Most of the lake and stream communities lack large cool and warm-water piscivores, and many lack piscivores altogether.

Parks provide ideal settings for protecting biodiversity. However, the same threats to biodiversity outside parks are often present inside parks, and Algonquin Park is no exception. The main threats to fish biodiversity in the Park are commercial logging, recreational fishing, introduced species and climate change. These impacts must be minimized through proper management based on sound science, otherwise the unique fish biodiversity of Algonquin Park may be lost forever.

Additional Readings

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Genetic Research on Brook Trout and Lake Trout in Algonquin Park

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Advances in genetic technology over the past two decades have provided a variety of molecular genetic marker systems that are enabling new insights into the historical and contemporary processes that influence fish biology. Genetic research on brook trout (*Salvelinus fontinalis*) and lake trout (*Salvelinus namaycush*) in Algonquin Park is allowing us to examine issues ranging from the phylogeographic history of these species to the effectiveness and effects of past stocking efforts and reproductive success of individual fish.

Phylogeographic analysis of brook trout populations within the Park using mitochondrial DNA (Danzmann and Ihssen 1995) showed that the mitochondrial structure and diversity of Park populations primarily reflects post-glacial recolonization events, despite intensive stocking throughout most of the 20th century. By contrast, analysis of these same populations with polymorphic isozyme markers shows that past stocking events have had major impacts on native populations of brook trout (Ihssen *et al*., unpublished data). Most of the extant brook trout populations within the Park contain at least some hatchery genes, which vary by watershed and proximity to the Highway 60 corridor. This mixed ancestry may have a direct influence on population-level fitness and life history characters, as growth rates within populations vary with the extent of hatchery ancestry (P. Ihssen, pers. comm.). Evidence from experimental stocking may also indicate variable fitness of mixed-ancestry (hatchery / native) brook trout, based on the extent of wild versus hatchery genes (Quinn and Wilson, this volume). This has obvious implications for management of brook trout populations within the Park, and the development of a Dickson Lake brook trout broodstock for stocking in the Park. Other current research is examining the metapopulation dynamics of brook trout populations in the Park, using microsatellite DNA markers and tagging data to evaluate movement among streams and lakes, the importance of tributary streams to lake populations, and connectivity among habitats.

Recent work on brook trout in Scott Lake has examined the behavioural genetics and reproductive success of individual fish during spawning, using microsatellite DNA (Blanchfield *et al*., in prep). Despite observed attempts by multiple males to spawn with individual females, the majority of broods were fathered by single males. Male reproductive success varied with body size, over one third of the observed broods resulted from fertilization by two of the largest males. Smaller female brook trout showed no preference for mating with related versus unrelated males, whereas larger brook trout only mated with unrelated males.

Populations of lake trout within the Park primarily originated from a Mississippian refugium after the last deglaciation event (Wilson and Hebert 1996, 1998). Isozyme analysis of Park populations has so far failed to detect additional populations of the Haliburton ‘glacial relict’ lake trout (Ihssen *et al*. 1988), but have detected some unique biodiversity elements. Investigation of a unique ‘silver’ morphotype in Kingscote Lake has confirmed the genetic uniqueness of this population, despite intensive stocking between 1925 and 1985 (Yott 2000). Current research efforts are focused on identifying other unique biodiversity elements and using molecular markers to quantify the historical demographics of lake trout populations in relation to carrying capacity and management practices.

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The Importance of Plankton to Fish: Food Web Studies through Integrated Sensors

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The rates of many ecological processes, including those such as growth and consumption, are strongly correlated with body size in freshwater organisms (Peters 1984). Boudreau and Dickies (1992) developed a model of energy transfer between adjacent trophic groups (e.g., zooplankton to fish) based on the fact that a) specific production (production: biomass) of the predator is size dependent, b) the product of predator growth efficiency and the predator mortality imposed on the prey is size dependent, and c) the predator: prey size ratio is constant for all adjacent trophic groups. Thiebaux and Dickie (1992) presented an analytical solution to this model that can be visualised as a biomass size spectrum –a double-logarithmic graph of body mass (X-axis) against normalized biomass (total biomass per logarithmic mass interval divided by the width of the interval). Such a graph consists of a series of parabolas of constant curvature, each one corresponding to a major trophic grouping (algae, zooplankton, fish). The parabolas are arranged along a roughly straight line of negative slope with each parabola shifted constant distances down the Y-axis and along the X-axis relative to the previous one (Kerr and Dickie 2001).

Working with mean annual biomasses measured in logarithmic size intervals for all pelagic organisms in Lake Ontario, Sprules and Goyke (1994) estimated all parameters required for a complete specification of the biomass size spectrum and its componenet parabolas. They also showed for Lake Ontario that estimates of seasonal zooplankton and planktivorous fish production derived from the Thiebaux-Dickie model conform closely to independent estimates based on egg-ratio or bioenergetic models. Since the food webs of Lake Ontario and Lake Opeongo are broadly similar (large salmon or lake trout (*Salvelinus namaycush*) feed on smaller alewives (*Alosa pseudoharengus*) and cisco that feed on a small-bodied assemblages of zooplankton), it is reasonable to use the Lake Ontario size spectrum to predict annual lake trout production in Lake Opeongo from data on zooplankton biomass.

Zooplankton biomass was estimated from repeated surveys along a linear transect in the upper portion of the south arm of Lake Opeongo during spring, summer and fall from 1998 to 2000 using an Optical Plankton Counter (Herman 1992). The mean and variance in the zooplankton biomass parabola for Lake Opeongo were specified from these data. This parabola was then shifted along the X and Y-axes of the size spectrum to the position expected for the Lake Opeongo fish parabola using the Lake Ontario parameters. The biomass of fish in the bodymass range occupied by lake trout from 4 to 12 years of age (approximately 100-4000g) was converted to annual production through multiplication by size-dependent annual production:biomass (P:B) ratios (Banse and Mosher 1980) to give a value of 8197 kg (bootstrapped 90% confidence interval 2,249-47,670 kg) for the whole lake. This value compares to 4,060 kg computed for the same aged fish from creel data and virtual population analyses for the period 1960 to 1983 (Carl *et al*. 1991).

These values compare well considering that the only sampling date used from Lake Opeongo was for zooplankton and that the parameter values are from Lake Ontario. The production estimate from the size spectrum is higher than that based on lake trout population to date, but it must be realised that any fish falling into the size range used for lake trout are included (e.g., lake whitefish-*Coregonus clupeaformis*, burbot-*Lota lota*). Bootstrapped variability in the size spectrum prediction is very large indicating high sensitivity of the model to some parameters. These results suggest some promise for the use of easily collected body size and biomass data on one group of organisms as a basis for establishing the general range within which production of a target group of organism falls.

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Detailed Lake Bathymetry Maps: Uncovering the Underwater World of Algonquin Park Trout

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New methods of collecting and processing bathymetric data provide a versatile tool for fisheries research and assessment. Geographic Positioning System (GPS) equipment and depth sounders are linked to a laptop computer to simultaneously collect and record water depth and geographical position on a lake. This removes some of the restrictions that applied to the older depth sounding methods, such as the need to drive the boat in a straight line and at a constant speed to and from known reference points. More data can be collected in a given amount of time, and the increased detail may reveal features not previously recorded in a lake, such as offshore shoals or troughs. Once the data have been collected and stored, they can be used for many different purposes, including map making, habitat assessment, project planning and interpretation, and analysis of other spatially-referenced data. Mapping software can create traditional-looking contour maps, as well as cross sections, 3-D maps, and many other types of images. Areas and volumes of the entire lake or subsections of a lake can be quickly calculated. The data are especially useful for planning projects that use depth-stratified sampling, or to show where gear with specific depth requirement can be set. Maps can be quickly displayed and modified on the computer screen, and maps with sampling locations can be printed for field use. The real value of the data can be realised if integrated into a full-featured Geographical Information System (GIS).

Additional Readings

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Predicting the Spread and Impact of Introduced Fishes in Algonquin Park, Ontario

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Most lakes in Algonquin Park originally lacked large cool and warm-water piscivorous fishes (e.g., pike (*Esox lucius*), walleye (*Stizostedion vitreum*), basses) as the result of early isolation following the last Ice Age. The authorized introduction of smallmouth bass (*Micropterus dolomieui*) began in the late 1800s and continued into the mid-1900s. More recently, the unauthorized introductions of northern pike, rock bass (*Ambloplites rupestris*), largemouth bass (*Micropterus salmoides*) and walleye have led to the establishment of reproducing populations in many Algonquin lakes. The objectives of the current study are to identify lakes in Algonquin Park that have suitable trophic, physical and chemical conditions for these introduced species; and, to identity current and potential impacts of these species on native fish communities.

To identify lakes susceptible to colonization by introduced species, separate discriminant function analyses (DFA), were used to predict the presence or absence on eight trophic, five physical and five chemical parameters measured in 2,809 Ontario lakes (excluding Algonquin lakes) south of 48°N, and applied to data for 245 Algonquin lakes. Lakes predicted to be suitable for an introduced species (i.e. predicted presence) were considered to be susceptible to colonization.

For all introduced species, the trophic data were most important in the discriminant analyses, and the physical and chemical data were of limited importance. The discriminant models correctly predicted the presence of the introduced species in southern Ontario lakes at rates ranging between 88.9% and 92.2%, and at rates between 38.5% (rock bass, *Ambloplites rupestris*) and 100% (walleye) when applied to Algonquin lakes. Northern pike and walleye were predicted to invade the greatest number of Algonquin lakes, 63 and 65 respectively.

To identify the potential impact of the introduced species on native fish communities, the distributional relationships between each introduced species and native species was measured using the Jaccard similarity coefficient based on the Ontario lake dataset. Relationships between an introduced species and a native species with a low Jaccard coefficient (<0.20) were classified as predator-prey, competitive of other (e.g., sample bias). Twenty species native to Algonquin were shown to be negatively associated with all of the introduced species.

Lakes containing fish communities likely to be impacted by introduced species were ranked according to potential introduced colonizers and number of native fishes negatively impacted (i.e. prey, competitor) by the introduced species. Crotch Lake was the only lake predicted to be invaded by all five species considered. Twenty-two lakes contained 10 or more native species likely to be impacted by the introduced species with Lake Travers (19 species), Lake Opeongo (17) and Catfish Lake (15) having

Calibration of Index Netting Methods: How Many Fish are in the Lake?

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Index fishing is a standard method of fishing. Standards are defined for the type of gear, its method of deployment, when it is used (time of year, time of day), and the design for selecting sampling sites. These standards ensure that the data collected on different lakes are comparable. Ontario's Fisheries Assessment Unit (FAU) network has developed several standards aimed at different species of fish. Spring Littoral Index Netting (SLIN) is a method for assessing lake trout abundance and mortality rate (Lester *et al.* 1991). It sets small mesh gillnets (25, 38, 52 mm) in the littoral zone during the spring for 1.5 hour periods. Because large fish are entangled, not wedged, by the gear it is a low impact method of sampling the adult segment of the population.

An exploitation model developed by Shuter *et al.* (1998) supplies criteria for evaluating the status of lake trout populations based on abundance and mortality rate (Lester and Dunlop 2000). In order to use SLIN in testing whether abundance is being sustained above critical levels, the relationship between SLIN, catch per unit effort (CUE) and lake trout abundance must be determined. This calibration is being done on FAU lakes where estimates of lake trout abundance have been obtained from mark-recapture studies or angling harvest data. The results indicate that CUE increases with density, but this relationship is dependent on the lake surface area. For a given fish density (population size/lake area), CUE is higher on larger lakes. The results supply a formula for estimating lake trout density from index fishing, CUE, and lake area. Because confidence limits placed on this estimate are large, SLIN will not supply a precise estimate of lake trout abundance for an individual lake. However, the method does supply a rapid assessment technique that can be used to evaluate the status of a population of lakes.

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Spatial Ecology and Density Dependent Processes in the Ecology of Smallmouth Bass *(Micropterus dolomieui)* – the Juvenile Transition Hypothesis

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A long-term study on the ecology of smallmouth bass (*Micropterus dolomieui*) in Lake Opeongo points to some basic spatial processes that appear to be important in their population ecology. In general, this process is based on the spatial spread of juveniles (ages 1-4) within the lake. I develop this hypothesis based on a series of field studies conducted at Opeongo as well as growth and abundance data from the creel census. There are a number of results that are important in this story including: 1) nest site fidelity; 2) young-of-year dispersal from nests; 3) adult home range location and use, and 4) new results on the home range of juvenile smallmouth bass. The creel census reveals that density dependent growth occurs only during the juvenile period in the age range of 2 to 4 years. Together, the information points to the juvenile period as the life stage where bass confront limiting resources in Opeongo. The spatial spread of juvenile bass from spawning areas to other areas of lakes is what I refer to as the juvenile transition hypothesis.

Effects of Climate on Smallmouth Bass (*Micropterus dolomieui*) Populations: Sixty Years of Research at Lake Opeongo and Beyond

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Scientists from both the University of Toronto and the Ontario Ministry of Natural Resources have been studying the smallmouth bass (*Micropterus dolomieui*) population of Lake Opeongo since 1936. This work has demonstrated strong and consistent associations between short and medium term climate variability and variability in growth and reproductive rates of this population. In some years, climatic influences are partially masked by density-dependent processes, however regression techniques can be used to filter out these effects and clarify the consistent nature of climatic influences. Short-term studies from other lakes in the general area of Algonquin Park further demonstrate the important role of climate in shaping significant events and processes in the life history of this species (e.g., timing and duration of the spawning season, larval development times, young of year growth rates, winter survival rates). Quantitative models based on these studies are capable of accounting for both the current position of the northern zoogeographic boundary for the species, and the response of that boundary to climate warming. A northward extension of the boundary by up to 500 km is possible under reasonable climate change scenarios.

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Home Range and Habitat Preferences of Adult Lake Trout (*Salvelinus namaycush*) in Lake Opeongo, Algonquin Park, Ontario

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The description of home ranges is important for the determination and protection of key habitat areas. Movements of adult lake trout (*Salvelinus namaycush*) have been under investigation in Lake Opeongo, Algonquin Park, for three consecutive years. A total of twenty-four fish (mean fork length 565 mm, range 449-770) have been implanted with acoustic transmitters. The objective of this research was to determine the extent of home ranges and the habitat preferences of adult lake trout in a large (58.6 km^2) inland lake system. Home ranges (95% Kernel area) for individual adult lake trout in Lake Opeongo ranged from 0.8 to 10.1 km^2 and core areas (50% Kernel area) ranged from 0.2 to 2.2 km^2 (n=20). In summer, home range sizes ranged from 0.4 to 9.0 km^2 and core summer ranges were from 0.07 to 2.3 km^2. In the year 2000, seasonal use of summer core areas was examined. Adults tend to use their summer ranges to some extent in the spring, as 78.5% of spring fixes fall within summer ranges. In the fall, only 38.1% of fixes fall within the summer ranges, and these tended to fall on the edges of summer use area. Only two of six fish visited their summer core areas during the fall (6 fixes of a possible 286). The importance of site selection in the reproductive ecology of lake trout is well documented. Using an existing model of sedimentation processes in lakes (Rowan *et al*. 1992) and a geographic information system (GIS), we mapped the extent of erosive habitat in the lake. Habitat variables (slope, depth, and fetch) were summarized for each fish location during the spawning period in each year. Positions of lake trout were in areas of mean fetch equal to 1.5 km, mean depth of 5.1 m, and mean slope of 10.6% (n=50 fixes). We then used a GIS to identify areas that matched those habitat values (mean +/- 1 SD) to identify potential spawning areas. This method correctly identified 19 of 21 known spawning sites, as well as some areas used by spawning females in an earlier telemetry study (MacLean *et al*. 1981). Depths of traditional fall netting sites are shallow (3.1 m) compared to areas in which telemetered lake trout were found during evenings of the spawning period. The implications of this result are significant in terms of future assessment and restoration of reproductive habitat for lake trout.

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Influence of Food Web Structure on the Growth and Bioenergetics of Lake Trout *(Salvelinus namaycush)*

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Most fish species tend to feed on larger prey as their size increases. The lack of suitable prey during critical periods of their life can prevent them from shifting diet to larger prey and also from reaching larger body sizes. In this study, we compared the energy budget of lake trout (*Salvelinus namaycush*) populations with contrasting food webs. Non-piscivorous lake trout (NPLT) populations reached a much smaller size and grew at a much slower rate than piscivorous trout (PLT) populations. Food consumption rates were on average, 2-3 times higher in NPLT when they were expressed on a wet weight basis. However, only a slight difference in their energy intake was detected (less than 10%) once consumption rates were corrected for differences in prey caloric content. Growth efficiency was about two times lower in NPLT compared to PLT, while their metabolic costs were higher and assimilation efficiency was lower.

It is most likely that the increased metabolic costs were associated with higher foraging costs, since more feeding attempts must be made to acquire a given quantity of food when fish are feeding on smaller prey. Furthermore, the portion of indigestible matter is likely to be higher in the diet of NPLT than in PLT (e.g., chitin versus bone). These results are consistent with theoretical models of fish growth that have showed that lake trout must have access to larger prey, even if they are rare, to reach larger body sizes. Our study also illustrates how the restructuring of a prey community by the arrival of an exotic species into a food web could alter the growth rate of a top predator. Furthermore, our study suggests that age at first maturity is influence by growth efficiency in indigenous populations of fish. Therefore, the dynamic of a population and its vulnerability to exploitation are likely to be influenced by their energy allocation strategy.

Use of Topographic Indices to Predict Potential Brook Trout *(Salvelinus fontinalis)* Habitat in Lakes on the Canadian Shield

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Brook trout (*Salvelinus fontinalis*) are closely linked to the hydrology of the watersheds they inhabit. Groundwater inputs in the form of surface or sub-surface flow at lake and stream margins are important features of spawning (Curry and Devito 1996; Blanchfield and Ridgway 1997) and young-of-year (YOY) habitat (Curry *et al*. 1997; Biro 1998). Landscape features such as topography can be used in a geographical information system (GIS) to map these areas of potential saturation and water accumulation with the use of a topographic index (TI). The $\ln(a/\tan\beta)$ is a widely used TI in hydrology derived from the soil saturation component of Beven and Kirkby's (1979) TOPMODEL, where a is the up-slope area contributing water to a given cell and β is the slope of that cell.

A TI was developed for Algonquin Park, Ontario, to identify potential brook trout habitat and associated sub-catchments that sustain them. A field survey of 21 lakes in the Park with self-sustaining populations of brook trout was also undertaken to determine the distribution of hydrological features used by YOY brook trout. Large values of the topographic index (representing high inputs of groundwater) derived in a GIS environment were found to correspond closely to field locations of potential brook trout habitat in lakes. Only 11% of cells (from a total of over 13500) from the 21 lakes surveyed have TI values large enough to be considered potential brook trout YOY habitat. YOY use of these seepage and stream habitats was seasonal with few being used in both spring and summer. This is possibly associated with their strong ($P<0.01$) preference for colder, shallower, and narrower habitats typical of small groundwater dominated streams. The number of potential seepage and stream habitats increases asymptotically with lake surface area ($R^2=0.74$). The asymptote of the relationship occurs at a lake surface area of 200 ha.

Provincially, 93% of all brook trout lakes have a surface area of less than 200 ha. It appears that lakes greater than 200 ha have a lower density seepage and stream habitat per kilometre of shoreline despite the significant increase of catchment area with increased lake surface area ($R^2=0.85$). The limited number of nursery habitats in larger lakes may be attributed to the increasing complexity of drainage networks (i.e. higher order streams) in larger catchments. Thus larger lakes have proportionally the same amount of habitat; however the number of YOY access points to that habitat decreases in larger lakes.

Over 50% of the potential lake shore habitats found in the field were not present on the Ontario map system. However, preliminary results show that YOY brook trout show patterns in their use of different TI values at different times of the year and in different habitats. Knowledge of the spatial patterns of brook trout groundwater habitat use is therefore required to protect these areas from anthropogenic sources of disturbance. This large scale GIS and TI approach offers a means of predicting the location of potential habitat sites based on their physical characteristics.

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Extraordinary Results of Innovative Stocking of Brook Trout *(Salvelinus fontinalis)*

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Domestic hatchery-reared brook trout (*Salvelinus fontinalis*) rarely establish wild (self sustaining) populations when stocked in lakes. The reasons for this are unclear but must be related to both deficiencies of habitat in recipient lakes or the fish themselves; generations of rearing in the hatchery seems to reduce the fitness of brook trout (eg., Vincent 1960). We stocked three lakes in the western uplands of Algonquin Park in 1991 with spring fingerlings spawned from wild adults and observed both reproduction and evidence of extraordinarily high survival. The recipient lakes were Thunder, Whitespruce and Eu (the latter two are connected and effectively form one lake). All three lakes are small (<18 ha) with depauperate fish communities and maximum depths >10 m (details are available from NWSQ). None of the lakes had brook trout prior to stocking. Spawn were collected in November 1990 from three Park lakes: Scott, Charles, and Salvelinus, incubated over winter in a private hatchery, and stocked by helicopter in May 11. Thunder Lake received 950 fish from Salvelinus and Charles lakes, and Eu-Whitspruce received a total of 2250 fish from all three donor lakes.

In November of 1999, the Thunder Lake population was sampled via two overnight gill net sets of two panels each. Fifteen brook trout with a mean length of 42.38 cm (38.0-49.5 cm) were caught, clearly comprising one cohort of F_1 (stocked) fish. Eu and Whitespruce lakes were sampled in September of 2000, using four overnight gill nets of two panels each. Forty-six fish were caught, of which 36 were greater than 30 cm (maximum 45 cm), 9 were 20-30 cm, and one 10 cm. Based on length-at-age data for brook trout from the Park (Quinn *et al*. 1994) , the smallest fish was certainly produced from reproduction of the original planted fish, which seems probable for most or all of the 20-30 cm fish as well. Juvenile brook trout were observed in the shallows of Eu-Whitespruce in the spring of 2001, confirming wild reproduction in at least one of these lakes. Wild brook trout in Algonquin Park rarely live past 5 years of age (Quinn *et al*. 1994) and survival of stocked brook trout is poor (e.g., Fraser 1972). Results of our netting are therefore suggestive of exceptional survivorship.

Brook trout from the three source populations were readily distinguishable based on genetic variation at six isozyme loci. Assignment tests based on multilocus genotypes of individual fish correctly identified the population of origin for 94% of brook trout from the three source lakes. Assignment tests were similarly successful in resolving the ancestry of brook trout in the stocked lakes. All but one of the captured Thunder Lake brook trout originated from Salvelinus Lake. Similarly, Salvelinus Lake brook trout showed the greatest contribution (67%) to the Eu-Whitespruce populations, although Charles Lake brook trout made up 22% of the sample collection. The genotypes of several fish indicated their mixed ancestry, primarily between Salvelinus and Charles Lake brook trout. The contribution of success of brook trout from the three source populations varied in proportion to the extent of introgressed hatchery ancestry (Ihseen *et al*. unpublished data). The combined survivorship and genetic data indicate that wild stocking and maintaining the genetic integrity of wild source populations may result in enhanced survivorship and reproductive success of stocked fish.

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Altered Energetic Pathways: The Effect of Yellow Perch (*Perca flavescens*) on the Resource Use of Lentic Brook Trout *(Salvelinus fontinalis)*

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We determined the trophic position and resource use of brook trout (*Salvelinus fontinalis*) in six Algonquin Park lakes which varied in fish community composition from cyprinids only, to cyprinids and white sucker (*Castostomus commersoni*), to cyprinids, white sucker and yellow perch (*Perca flavescens*). Brook trout showed distinct changes in trophic position and resource use between community types. The presence of yellow perch resulted in higher trophic position of brook trout, an increased use of profundal prey and a high degree of piscivory on yellow perch. Mean trophic position of brook trout <25cm fork length was 3.2 in all community types. The trophic position of brook trout >25 cm fork length remained constant at 3.2 in cyprinid only communities, increased to 3.5 when white sucker was present and to 3.9 when both yellow perch and white sucker were present in the lake. Gut content analysis indicated a significantly higher occurrence of piscivory in lakes containing yellow perch with perch being the preferred prey. Carbon isotopic signatures of brook trout tissue indicated brook trout utilize pelagic resources in cyprinid only communities, a mixture of pelagic and benthic resources in white sucker communities, and a mixture of benthic and profundal resources in communities containing yellow perch. Gut content analysis indicated a reduced occurrence of chaoborus, trichoptera, odonata, and ephemeroptera when yellow perch were present in the lake. Brook trout dramatically alter their resource use and trophic position in response to the presence of potential competitors such as white sucker and yellow perch in the fish community. This alteration of food web position will have implications for growth, population stability and the effect of fishing pressure on brook trout populations.

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Reproductive Ecology of Brook Trout (*Salvelnus fontinalis*) in Algonquin Lakes

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The study of mating systems focuses on the interactions of males and females from the perspective that all individuals compete to maximize their reproductive success. Although there has been extensive study of reproductive patterns in salmonid fishes (salmon, trout, char), there is limited understanding of the reproductive interactions that occur under natural conditions. Early research on the reproductive requirements of brook trout (*Salvelinus fontinalis*) in Algonquin lakes were fundamental in establishing the association between groundwater flow through permeable, lake bottom substrate and spawning site location (Fraser 1982, 1985). These findings provide the framework from which to test theoretical predictions on the relationship between resource quality (groundwater flow) and reproductive success. I studied the reproductive strategies of lake-spawning brook trout at Scott Lake, Algonquin Provincial Park, and relate these findings to current mating system theory.

Breeding was characterized by competition among females for spawning sites that contain upwelling groundwater. Extensive re-use of spawning sites and female removal experiments indicated that groundwater sites were a limiting resource. Egg survival experiments showed that very few spawning sites used by females during the four years of this study had rates of groundwater flow that would result in greatest offspring survival (20 $\mathrm{mL \cdot m^{-2} \cdot min^{-1}}$). Female body size was an important component of reproductive success (number of eggs surviving to hatching). Larger females were more fecund and, in general, spawned earlier and at better quality sites than small females. At the population level, only 15% of eggs deposited by females were estimated to survive to hatching. Reproductive success of females is constrained by the limited number of spawning sites that have high rates of groundwater flow in this population.

Males competed for access to females and were present in greater numbers than females throughout the spawning season. Mate searching by males included many repeat visits to females and allowed males to predict female readiness to spawn. Large body size conferred a reproductive advantage to males searching for mates, but searching behaviours became restricted with increasingly male-biased sex ratios. Peripheral males exerted a mating cost to dominant males and females. The potential for stolen fertilizations was greatest for males paired with large females due to the presence of numerous peripheral males. Latency to spawn by females increased when paired with relatively small males, and resulted in females obtaining a larger spawning partner and size-assortative mating. Genetic analyses of multiple-male spawning show a first male advantage in fertilization success, the number of males around females are not indicative of the number of males obtaining paternity, and that male reproductive success is highly skewed, with a large proportion of males not contributing to future generations.

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The Lake Trout (*Salvelinus namaycush*) Fishery of Smoke Lake, Algonquin Provincial Park, Ontario: 13 years after Major Changes in Fishery Regulations

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Smoke Lake, Algonquin Provincial Park, Ontario has a surface area of 607 hectares and mean and maximum depths of 16.4 and 56.5 meters. Development includes 89 shoreline leases, a public boat launch and parking area, and a hangar and docks operated by the OMNR. In 1989 the following regulations were implemented: (1) daily and possession limit of 2 lake trout (*Salvelinus namaycush*) (from 3); (2) lake herring (*Coregonus artedii*) was banned as bait; (3) closure of the lake trout (*Salvelinus namaycush*) season on September 30 (from October 10); and, (4) lake trout between 40 to 56 cm in length must be released. Long-term (1978-2001) trends of targeted angling effort, harvest and catch, estimated from creel surveys (n=10), and corresponding trends of population size, mean length, and growth rates of spawning lake trout, estimated from mark-recapture studies (n=15), were presented. Effort was very high (>5 rod-hrs/ha/yr) for 6 of 7 years surveyed before 1989 and it declined from 1980 (8.8 rod-hrs/ha/yr) to 2001 (3.1 rod-hrs/ha/yr). Harvest from 1978-1980 exceeded a conservative estimate of sustainable yield (0.73 kg/ha/yr) based on the number of fish species in Smoke Lake (n=17) (Marshall 1996). However, harvest did not exceed sustainable yield between 1981 and 2001. The average number of lake trout caught and kilograms harvested per rod-hour (CUE and HUE, respectively) declined from 1978 (0.13 and 0.2) to 1982 (0.08 and 0.07) and then increased to 2001 levels (0.3 and 0.29). An estimate of the number of spawning lake trout increased from 1978 (168) to 1989 (251) through to 2000 (1026). Conversely, mean fork length (mm) of spawning trout decreased from 1978 (643) to 1989 (633) through to 2001 (574). Length increments were used to model growth rates (Ricker 1975). Prior to 1990, a lake trout with a fork length of 450 mm grew an average of 282 mm in 10 years. However, from 1990 to 1995 and 1996 to 2001 the same fish grew an average of 237 and 216 mm respectively, over 10 years.

Since implementation of the regulations in 1989, the estimated number of spawning lake trout has increased rapidly, coinciding with a decrease in mean length and growth. In 2001, annual effort targeted toward catching lake trout and average time require to catch lake trout was lower than in any other year. Also, average harvest of lake trout per hour was heavier than in any other year and , harvest was at a sustainable level. The impact of the slot-size regulation may be determined by comparing long-term trends with those from Lake Opeongo, Algonquin Provincial Park.

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CONCLUDING REMARKS

Algonquin Fisheries Symposium in Perspective

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Although brief, this meeting has broad span; indeed, most of the topics pertinent to a modern discussion of fisheries biology and conservation were addressed here and many innovative ideas and approached were brought forward.

1. Biodiversity/genetics/species invasions. Nick Mandrak presented an innovative analysis of post-glacial zoogeography that explained the prevalence of cold-water fish communities in Algonquin Park as a relict phenomenon arising from the barriers to dispersal that restrict the distribution of many key warm and cool-water invaders: lake trout (*Salvelinus namaycush)*, northern pike (*Esox lucius*), walleye (*Stizostedion vitreum*), and bass. The talk also gave us key insights into the potential effects of these potential invaders on brook trout (*Salvelinus fontinalis*). David Browne presented a stable isotope analysis of brook trout (*Salvelinus fontinalis*) trophic and habitat responses to another cool-water species yellow perch (*Perca flavescens*). Chris Wilson outlined molecular genetics approaches to brook trout conservation problems in the Park.

2. Fisheries Assessment. Nigel Lester presented an analysis of Index netting protocols used in fish population monitoring, discussed their calibration, and evaluated their quantitative performance. Brian Monroe and Glenn Forward assessed the impact of slot size limit imposed on the lake trout fishery 13 years ago in Smoke Lake.

3. Habitat Preference/Assessment. Lori Flavelle looked at the seasonal difference in habitat use by lake trout using radiotelemetry, with particular reference to individual variability. She also made innovative use of a model of wind-induced, sediment transport to predict the locations of lake trout spawning areas. Greg Betteridge provided an in-depth look at what GPS based bathymetric maps can do to enhance the precision of habitat characterization studies.

4. Spatial Ecology. Mark Ridgway employed spatial approaches to analyze smallmouth bass (*Micropterus dolomieui*) habitat use at different times of the year and at different stages in their life cycle.

5. Climate Change. Brian Shuter examined the question of how climate generates both short-term and long-term variability by means of a statistical analysis of the long-term records of smallmouth bass (*Micropterus dolomieui*) populations in Lake Opeongo.

6. Watershed Processes. Although not a major topic of importance in the meeting, the work by Jason Borwick on groundwater mapping in watersheds and the importance of ground water seeps for brook trout, falls into this area.

7. Recruitment/reproduction in fish populations. Paul Blanchfield also looked at groundwater, but his

work was more directly focussed on spawning habitat requirements of brook trout.

8. Stocking. Norm Quinn and Chris Wilson described a stocking experiment that compared the post-stocking recruitment success of brook trout originating in different populations.

9. Bioenergetics. Gary Spurles outlined an approach to estimating potential fisheries yields using models based on community size structure and energetic principles. Rasmussen presented a bioenergetic comparison of lake trout from lakes where they become piscivorous and lake where they do not. This study re-addressed an old problem raised by Nick Martin about 30 years ago, and applied a modern technique involving radiotracer mass-balance.

Besides addressing a wide range of modern and highly pertinent topics, the meeting also brought forward a wide range of novel methodologies. These ranged form stable isotope tracer studies, bioenergetics based on radiocesium mass-balance, GPS and ground-water mapping techniques, modern molecular genetics techniques, models of wind-driven transport, survey netting techniques, radiotelemetry techniques and ground-water seepage measurement.

In addition to the broad range of topics addressed in the talks, the discussions following presentations and over coffee and meals also brought forward some interesting topics that peaked my curiosity, and on which it would be interesting to hear more.

1. Population recovery. How well have populations in the Park that have been inadvertently overfished recovered subsequently? Are there documented (or documentable) examples of depensatory effect such as species shifts in community structure that impede recovery of target species?

2. The Land-Water Linkage. What is the interface between fisheries and forest management practices in the Park? Are there (or have there historically been) examples of where the two different goals are at “loggerheads” with each other? What mechanisms have been implemented to ensure that they aren’t in conflict?

3. How are management decisions arrived at and implemented in Algonquin Park, and how does the decision-making, and policy implementation compare to what goes on in a comparable way in Quebec in the ZECs (Zone d’Exploitation Controlle)?

To conclude these remarks, a question arose that seemed potentially pertinent for another day, and that was “What about the future of Algonquin Park?” How successfully is it meeting the goals that it was established for originally, and in what direction are those goals likely to evolve in the future? I presume that these were to protect and manage for future generations a key segment of Ontario’s forest, fish and wildlife resources. Recently another ecosystem service, that of drinking water has hit the news big time in Ontario and in other parts of the country. Many urban and rural areas are becoming acutely aware of the need to secure high quality drinking water for the future, and the cost-effectiveness of watershed protection in meeting this goal, relative to technological substitutes such ultrafiltration of polluted sources. The fact that Algonquin Park contains the headwaters of several key drainages that account for a significant portion of the provinces purest water, will without doubt become a topic of increasing importance as the future unfolds and the population continues to grow. Ontario will also be facing a changing climate that may lead to reduced precipitation and runoff in certain regions, and it is already re-evaluating its energy policy, and possibly looking at its rivers for hydro-potential as well.

These might be fodder for an interesting discussion in some future year.

Finally I would like to thank the organizers for inviting me. I have for some years been involved in research in Algonquin Park, mostly through collaborations with Ontario Ministry of Natural Resource scientists that involve our joint supervision of graduate students. I have always found the research questions that the Park presents to be highly stimulating, and I feel that this opportunity to meet people engaged in such a wide spectrum of research and management with the Park has given me more insight into this beautiful place.